Digital Piano Key Action Diagnostic Properties

— Report —

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Introduction

When we need to choose a new digital piano, one of the key criteria must be the key touch. We might say, “too light/heavy,” “not responsive,” or even “just like a real piano.” However, our perception can be vague and imprecise. Of course, there are a large number of online review articles/videos, some of which are very helpful. However, most of them are still subjective and a small number of objective reviews tend to be limited in scope, e.g., just the static touchweight at the front of a key.

In response, this document presents three diagnostic properties and associated objective test methods that can be used to assess digital piano key actions. The information is based on a detailed case study which describes Roberto’s exploration of the difference between acoustic and digital pianos (https://archive.org/download/ogm21-piano/ogm21-piano.pdf). The case study touches upon the background, digital piano sound, key touch in some detail, and comparison of different digital piano key actions referring to actual models. However, the focus of *this* document is just the three diagnostic properties: touchpoint difference, direct action engagement timing, and inertia. Roberto thinks that these are the most essential criteria to assess digital piano key actions.

And there is another benefit of understanding these diagnostic properties. After the exploration, Roberto can now transfer skills between his acoustic and digital pianos more effectively. For example, although there is a subtle difference in how to play softly on his two pianos, he thinks that the skills acquired on the digital piano can be used properly on the grand piano by mentally/physically internalizing the necessary adjustments. So, the information in this document must also be useful for those who use both acoustic and digital pianos.

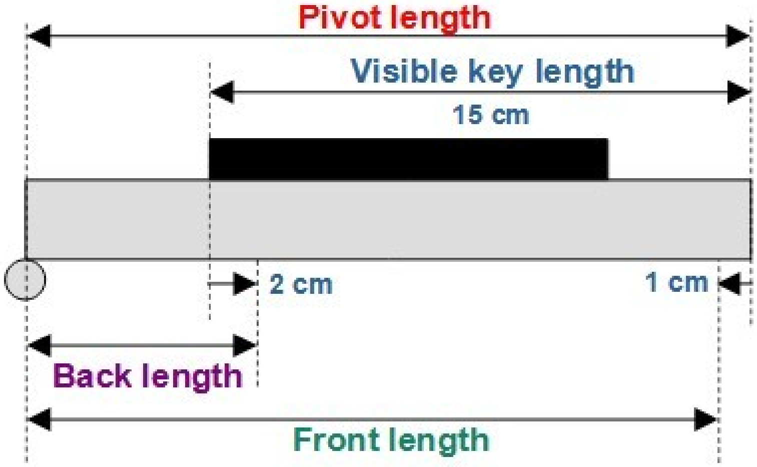
Disclaimer: This document is based on the experience of Roberto, an untrained piano hobbyist. So, the information here must be regarded as such. Note that much of the discussion revolves around Roberto’s two pianos: (1) 6’1” grand piano (ca. 1982) by a reputable manufacturer, and (2) digital piano (purchased in 2016, considered one of the best under $1,000).

Property #1: Touchpoint Difference

Probably, the most-often-discussed property of digital piano key action is static touchweight at the front of a key, measured with gram weights. [Note that there are different ways to measure static touchweight as discussed in the original case study.] So, this was the starting point for Roberto as well. When he actually measured his pianos, he was a little surprised. On his grand piano, the touchweight is about 25 grams (about 25%) lighter when the damper pedal is depressed. He never noticed the difference. On his digital piano, black keys are lighter than white keys, again, by about 25 grams (about 25%). He didn’t notice this either. It seems that this much of difference in static touchweight does not have a clearly noticeable impact. Yet, the key touch on his grand and digital pianos is so much different. The difference must come from something else.

One thing Roberto noticed clearly was the touchweight *difference* between the front and the back of each key, called ***touchpoint difference***. On his first digital piano, the back of each key definitely felt heavier. And this made it difficult for him to play his favorite pieces. His current digital piano does not have this problem. Not surprisingly, touchpoint difference is not an issue with his grand piano or any other grand pianos he tried. Note that there still are variations among acoustic pianos (grand or vertical). For example, smaller grand and shorter vertical pianos may have significant limitations in certain areas, including touchpoint difference.

So, Roberto chose touchpoint difference as the first diagnostic property. It is fairly straightforward to check it by casually comparing the touchweight at the front and the back of a key (practically any key, for that matter). Then, he learned that touchpoint difference is directly associated with the pivot length (from the front of a key to where the key is pivoted) and the force ratio (of the touchweight ratio between the front and the back). There is a relevant image in the original case study, also included on the next page.



Force Ratio = Front length / Back length

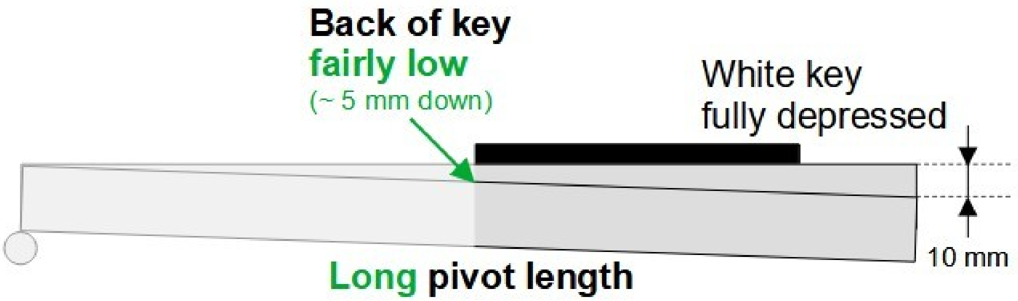
As for most grand pianos, the pivot length is fairly long and the force ratio is about two. That is, even on grand pianos, the back of a key is about twice as heavy as the front. But this is actually the best case. The force ratio of a typical digital piano can be between two (best) to four. For example, there is a digital piano model with the force ratio of about 3.5. Then, with the front touchweight of about 100 grams, the back touchweight is about 350 grams! This appears huge and must be much more significant than other types of variations involving static touchweight.

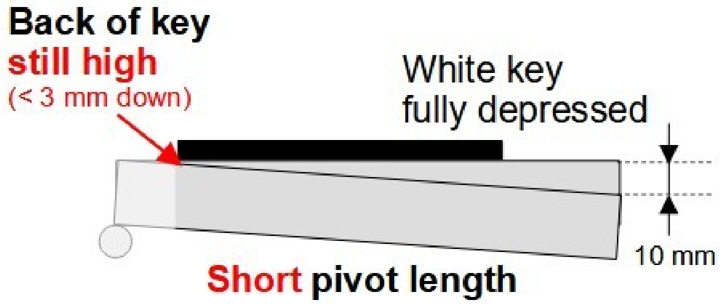
In addition to feeling the difference, there is a quick and easy way to quantify touchpoint difference. We just examine the slope of a fully-depressed key as described below.

Key Slope Test (**Slope Test**): When a key (any white key for this test) is depressed, how much the back of the key goes down is proportional to the pivot length. So, the amount of key drop at the back end can be used to quantify touchpoint difference.

On Roberto's grand piano, the result of the Slope Test is about 5 mm. His digital piano has a value of 4 ~ 5 mm, which is very good. If this amount is less than 3 mm, the digital piano may have poor touchpoint difference. If less than 2mm, touchpoint difference must be unmistakably poor. In comparison, Roberto also tried the test on his portable keyboard (often with fewer than 88 "springy" keys). The back of a key barely dropped; the force ratio must be enormous.

Now, a few millimeters of difference may seem a very small amount. However, that must be considered in the context of about 10 mm of key travel at front. Thus, even a small amount of difference in back key drop may actually be reflected in a noticeable slope difference. There is a relevant image in the original case study, also included on the next page.





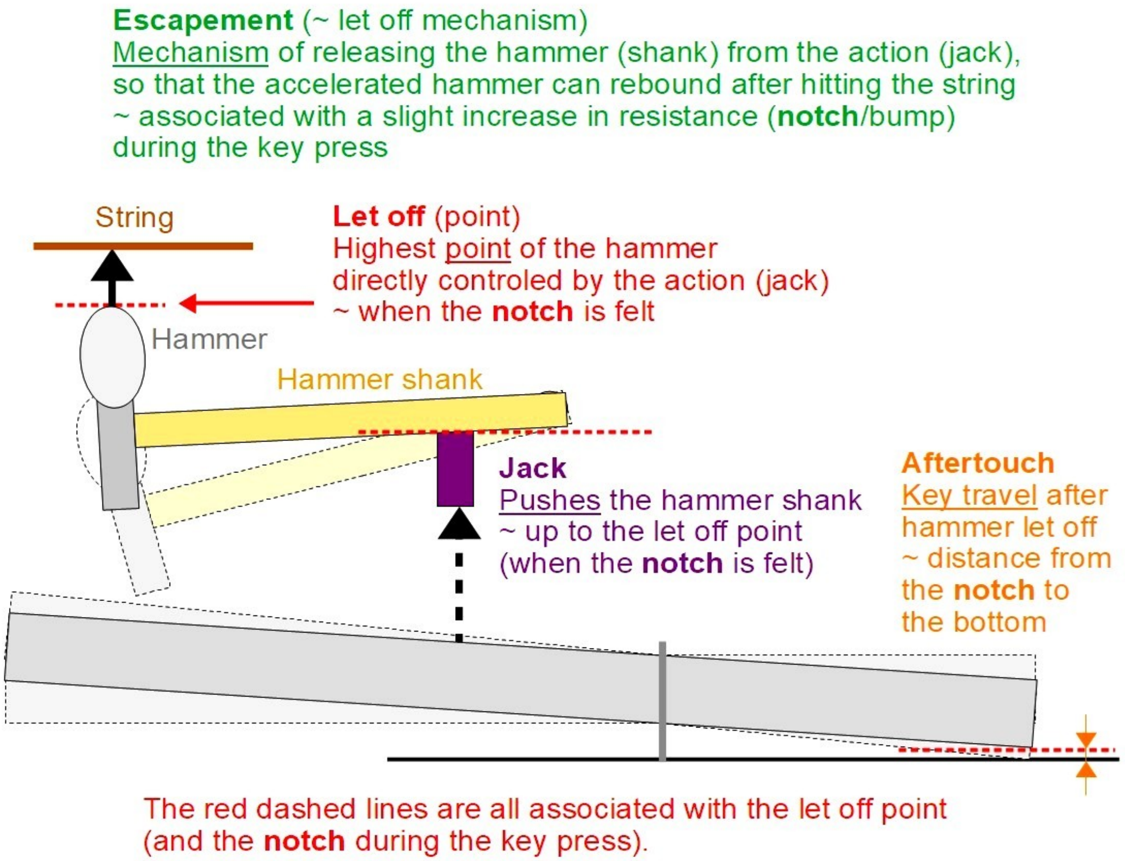
Strictly speaking, the maximum key travel at the front may be slightly different among models. If we need to be extra precise (e.g., for detailed comparison), the back key drop can be represented in terms of the percentage of the front key drop. For example, if the back key drop is 5 mm and the front key drop is 10 mm (typical), the value is 50%.

Touchpoint difference could affect the consistency of a key action much more than touchweight variations among different models (measured at front). And Roberto found out that even a very expensive hybrid piano has a surprisingly poor touchpoint difference. So, this must be one of the properties that need to be checked first.

Property #2: Direct Action Engagement Timing

One of the biggest challenges for Roberto on both of his pianos was how to play softly. In order to find out how to improve this skill, he carefully observed his grand piano's key action. This was when Roberto started to pay special attention to the *escapement mechanism*.

In an acoustic piano, when a key is depressed, the action (more specifically, the jack) pushes the hammer (strictly speaking, the hammer shank). This process begins immediately after the key press. When the jack reaches a certain point (called *let off* point), the hammer (shank) is disengaged from the jack, strikes the string, and rebounds. This rebounding is necessary for the string to stay vibrating (thus sounding) until the damper returns (as the key returns to the original position). There is a relevant image in the original case study, also included below.


Escapement (~ let off mechanism)
Mechanism of releasing the hammer (shank) from the action (jack), so that the accelerated hammer can rebound after hitting the string ~ associated with a slight increase in resistance (**notch**/bump) during the key press
String
Let off (point)
Highest point of the hammer directly controled by the action (jack) ~ when the **notch** is felt
Hammer
Hammer shank
Jack
Pushes the hammer shank ~ up to the let off point (when the **notch** is felt)
Aftertouch
Key travel after hammer let off ~ distance from the **notch** to the bottom
The red dashed lines are all associated with the let off point (and the **notch** during the key press).

Also, right around the let off point, the jack contacts a part called knuckle. And this process can be felt in the middle of the key press (at around 7 ~ 8 mm down from the original position) as a “bump” or “notch.” After that, the key is totally disengaged from sound production. That is, only about the first 3/4 of key press is directly associated with the hammer movement and thus sound production.

The most common practice of simulating escapement (or let off) in (advanced) digital pianos is to implement the sensation of the notch mentioned above. However, Roberto does not think that this is so relevant. He thinks that the more important aspect would be how accurately a digital piano simulates the interaction of the key and the hammer of acoustic pianos. In particular, by the time the hammer hits the string, the key is already disengaged from the hammer (shank). As a result, the sound production in acoustic piano must be considered as a sort of *indirect* process. Roberto thinks that *this* needs to be simulated.

Roberto also thinks that the understanding and mastering (mentally and physically) of this point must be helpful for being able to play softly. Now, playing soft does no longer appear to him as just depressing keys softly. It is the art of touching keys fast and strong enough for the hammer to move and reach the strings but gentle enough for the strings to make sounds at the intended level.

At this point, Roberto was convinced about the importance of the *initial* part of key press (prior to the let off point) for producing sounds. So, he identified his second diagnostic property, **direct action engagement timing**, and devised a test method for it.

Key Travel Limiting Test (Limiting Test): This is a test to estimate how much the early part of key press would affect the sound production. First, limit the maximum amount of key travel (e.g., by stacking coins in front of the key, if not “waterfall” style, or even placing a finger tip) and identify whether any key press within this limit can produce a sound. If there is no sound, increase the limit and retry. Then, the minimal amount of the (early) key travel to produce a sound is the result of this test, measured in mm. Or, it can be casually noted as “fast” or “slow” (in terms of timing).

On Roberto’s grand piano (and on other grand pianos he tried in stores), the result of the Limiting Test is less than 2 mm, i.e., “fast” or basically “immediate.” On his digital piano, it is about 5 mm (about half way to the key bottom), i.e., “slower.” The difference can certainly be felt when he compares the two pianos side by side.

Now, Roberto pays utmost attention to the beginning of each key press (when the hammer starts to move), especially when playing soft. In addition, by recognizing the limitation of his digital piano, i.e., “slower” response, he feels that he is now better prepared to transfer skills between the two pianos. [Note that there is a related discussion of repetition lever simulation in the original case study. However, Roberto does not think that it is as essential.]

Property #3: Inertia

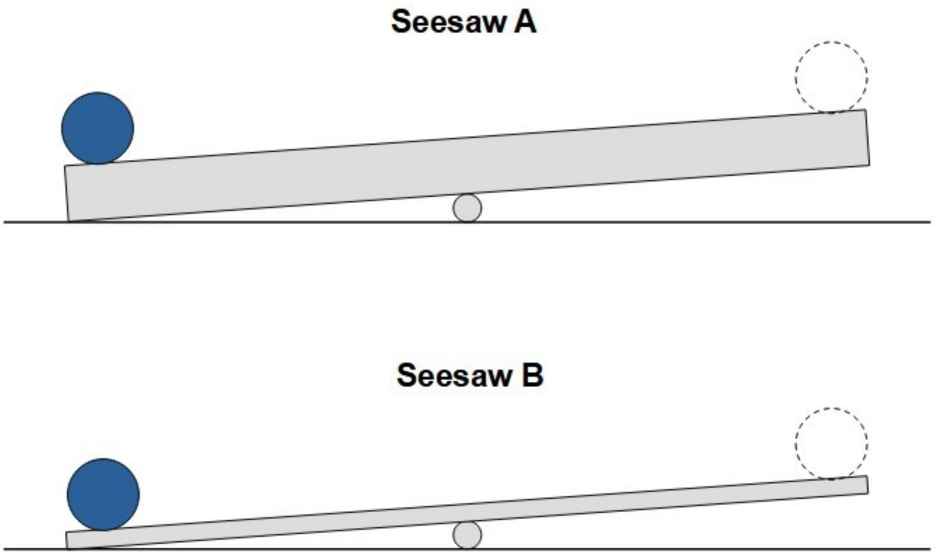
Roberto was also aware of another clear difference between his two pianos. When playing fast, the keys on his grand piano seem to rebound more actively than his digital piano. As a result, in spite of little static touchweight difference, the keys on his grand feel somehow “heavier.”

To find out why, Roberto continued to experiment. Then, when he was tapping keys very lightly (without making sound), he noticed that the keys on his grand piano are noticeably slower to rebound than those on his digital piano. This happens in just a fraction of a second and it did not seem to be something that can be easily measured. Nevertheless, the difference seemed crucial. He thought it must be associated with ***inertia***, the dynamic aspect of key touch. This became his third diagnostic property.

Technically speaking, inertia is the resistance of mass to accelerate or decelerate. That is, a heavier object resists to the change in speed more than a lighter one. For example, bass keys of a grand piano is heavier (to be able to strike heavier strings) than treble keys and thus slower to move.

Now, while static touchweight is about balancing and breaking the balance, inertia is about resistance to change, i.e., about moving. Thus, even though Roberto's two pianos have about the same amount of static touchweight, the keys on grand piano must have larger inertia.

In this connection, Roberto imagined two seesaws, one is heavier than the other. Regardless, two objects with the same weight can balance both of these seesaws. But the heavier seesaw would move (or come to stop) more slowly. This must be what is happening with the keys. There is a relevant image in the original case study, also included below.



Eventually, Roberto came up with a way to quantify the difference. The starting point was to repeatedly tap a key. If the rate of tapping increases, the subsequent taps will occur before the key returns to the original position. Then, he feels the force from the rebounding key. Roberto actually felt the increased force when the repetition rate increased to a certain point. This experience led to the following test.

Tapping Key Inertia Test (Tapping Test): This test is to estimate piano key inertia by repeatedly tapping a key lightly without making sound (with only a few millimeters of key travel), starting slowly, then gradually increasing the rate. The inertia must be related to the rate of tapping when the finger feels the increased force of the rebounding key *every time* the key is tapped. The result can be measured in terms of BPM, using a metronome. Or, it can be measured in terms of taps per second, using a loudly ticking clock/watch. It can also be casually noted as “large” or “small” (inertia). Naturally, a key with larger inertia must have a slower rate of repetition to have increased resistance. So, this test should be done on both bass and treble keys.

Note that this test involves a subjective element of “feeling” increased force. So, strictly speaking, it is not completely objective. However, this force detection part is binary, i.e., yes/no, and could even be mechanized, e.g., by creating a special test equipment. So, with this potential, we may still consider this test reasonably objective.

On his grand pianos, the result of the Tapping Test is about 300 ~ 360 BPM (5 to 6 taps per second), larger inertia on bass and smaller on treble keys. According to casual tests of other grand pianos in stores, the results were similar. On his digital piano, it is *at least* 480 BPM (8 taps per second) even on bass, which was the fastest Roberto could tap. Then, on his portable keyboard, he never really felt the force of a rebounding key; there is virtually no inertia and it felt “wimpy.” [Note that while digital piano actions in general have insufficient inertia, certain acoustic pianos may have excessive inertia due to a heavy action. That may be another problem.]

Now, Roberto felt that he nailed down something important. First, static touchweight is relevant only when keys are stationary. But in order to produce sound on an acoustic piano, keys must be depressed sufficiently fast, even for playing softly. Then, to move a stationary object, inertia must be involved. And when in use, the piano action is constantly on the move. So, it must be inertia that be more relevant *all the time*. And especially when playing fast, the fingers must be feeling a substantial force from rebounding keys due to inertia.

In the end, Roberto came to think that his perception of keys being “light” or “heavy” is more to do with inertia (dynamic touchweight) than static touchweight. Roberto thought that this point has rarely been clarified or emphasized in online reviews and comments.

Key Action Realism Index

Using the results of the three tests, Roberto formulated his own **Key Action Realism Index**. First, each of the three diagnostic properties can be assigned up to one point. That is, one full point is given to a “good” test result. Then, the best index would be three out of three (3/3). A digital piano key action with such an index must be able to simulate a grand piano action fairly well with respect to the three properties. Note that while the test is objective, this index is subjective because of the way scores are assigned. [Also note that the original case study presents a slightly different index with two additional points for actions of hybrid and “silent” pianos, resulting in the total score of five.]

Roberto’s assessment of his digital piano key action with respect to this index is as follows. One point for decent touchpoint difference (Slope Test), 0.5 points for so-so direct action engagement timing (Limiting Test), and 0 points for small inertia (Tapping Test). The total score is 1.5/3, which turned out to be fairly good. After (casual) testing at local stores, Roberto felt that not many digital piano key actions are better than this level. Only a very small number of digital piano key actions were assessed 3/3. [More details are in the original case study.]

Conclusion

This document introduces Roberto's three diagnostic properties. Touchpoint difference is a crucial element for key touch consistency. It must be considered as a prerequisite for a digital piano key action to be like a decent grand piano action. Direct action engagement timing is important for soft playing. It would be harder to transfer skills between pianos if they differ greatly with respect to this property. Inertia appears to be relevant to the sense of key "heaviness," even more so than static touchweight. A digital piano key action with small inertia may not be able to simulate the behavior of grand piano's rebounding keys, especially when playing fast.

In addition, these properties can interact in a complex manner. For example, Roberto always felt difficult to play fast *and* softly. And there is a good reason. While fast playing requires speed to deal with inertia, soft playing requires very fine control at the beginning of key press (with respect to direct action engagement timing). This certainly requires practice.

Then, for each property, Roberto presents an associated objective test method. The Slope Test simply measures how much the back of a fully depressed white key goes down. The result is proportional to the pivot length, the decisive factor for touchpoint difference. The Limiting Test measures the minimal key travel to produce sounds. The result is relevant to how "fast" the key responds to touch. The Tapping Test measures the rate of key rebounding, which is associated with inertia and the amount of force involved in movement. These tests can provide quantified results. However, as Roberto becomes familiar with the tests, he can now quickly estimate the outcome even without doing the actual measurement. This ability was quite useful when he visited local piano stores for testing.

Finally, Roberto hopes that this document be useful for other people as well. Especially with the objective test methods, we could share and compare the results openly. In a sense, the information in this document can be considered "open source." It can be jointly improved by the community, e.g., with respect to the (choice of) properties and test methods.

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